THE OPTICAL CONSTANTS OF SODIUM AND POTASSIUM.

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INTRODUCTION.

DURING the early part of the nineteenth century it was found that light was partially polarized by reflection from the polished surface of a metal, and also that plane polarized light became, in general, elliptically polarized upon reflection from such a surface. Later this was shown to be due to a relative change in the phase of the two components. The amount of this change was first measured in 1847 by Jamin,[1] who was thus enabled to calculate, theoretically, the index of refraction of the metal used. The next important work along this line was done by P. Drude,[2] who, about 1890, completed a series of measurements from which he determined the optical constants of most of the common metals.

A large amount of work has since been done, so that at the present time the optical constants of almost all of the metals are known, with the exception of a few of the more highly oxidizable ones. On account of the rapid oxidation of these, the difficulty has been to obtain a bright metallic surface and to preserve it long enough to examine its optical properties. The few attempts that have been made, while not at all satisfactory, have shown that these metals offer an interesting field for further investigation. In 1898 Drude[3] made a single measurement with sodium light reflected from the molten surface of metallic sodium. This measurement gave an index of refraction of 0.0045 which, if correct, means that light travels 220 times as fast in that metal as in air. After making due allowance for some possible errors, which Drude admits might have lowered his result, he says that the index could not be greater than 0.054. But this value is still remarkably low compared to the indices of other metals.

Since Drude's value of the index of sodium was made with sodium light, the question arises is there any connection between the low value of the index and the fact that the light used was of a wave-length peculiar

[1] Ann. Chim. Phys. (3), Vol. 19, p. 296, 1847.

[2] Ann. d. Phys., Vol. 39, p. 481, 1890.

[3] Ann. d. Phys., Vol. 64, p. 159, 1898.

to that emitted by the sodium molecule. Might this be a phenomenon akin to resonance, or is the value of the index equally low for all colors? These questions, together with the extraordinarily low index obtained by Drude, suggested the investigation reported on the following pages.

THE PREPARATION OF THE SURFACE.

In his work with sodium, Drude obtained a bright metallic surface by melting the metal in an atmosphere of rarified hydrogen, but found it necessary to renew the surface every few minutes on account of its rapid oxidation. During one of these attempts to remove the thin layer of oxide the vessel containing the sodium was broken and he was unable to verify his first determination. In the present investigation a number of preliminary experiments were made to find, if possible, a method of obtaining a more permanent surface, free from oxide. As the metal can be kept indefinitely under oil, it seemed possible that a bright surface might be obtained and preserved by melting the metal under some light transparent oil. The attempts, however, were not satisfactory for, while a bright surface could be obtained in this way, it would remain bright but a few minutes. Then again on account of the large surface tension and small density of sodium, the molten surface assumed a shape almost spherical, so that a comparatively large surface would be required in order to obtain a small part of the surface approximately plane.

Some efforts were made to obtain the desired surface by melting the sodium in a vacuum, but here, too, it was difficult entirely to prevent oxidation. It was noticed, however, that bright surfaces were often obtained against the inside wall of the glass container. These surfaces remained bright after the sodium had solidified and could be preserved indefinitely by filling the vessel with dry air or oil. This suggested the possibility of obtaining a permanent sodium mirror against a plane glass plate. With this end in view a number of experiments were made. Many of these ended in complete failure, but others gave more promising results. Finally, by combining and improving several plans, a method was devised which has proved quite satisfactory.

The Method in Brief.—A little box, or capsule (Fig. 2), was made by cementing two plane glass plates to the ends of a short iron tube, or ring, from the side of which a small glass tube extended. The latter tube was about 5 cm. long and at its outer end was drawn out so as to leave a very small opening. This capsule was suspended in a cylindrical glass vessel, in the lower end of which had been placed some metallic sodium. The vessel was then closed and evacuated and the lower end immersed in an oil bath, which was heated to a temperature of about

110° C. Meanwhile the suspended capsule was being heated up to approximately the same temperature by an electric current passing through resistance grids held against the glass ends. When the sodium below had melted the capsule was lowered until the small end of the glass tube dipped into the molten metal. Then by admitting dry air into the containing vessel the liquid sodium was forced up through the glass tube into the capsule and pressed firmly against the plane glass ends, thus forming two bright sodium mirrors. After the whole apparatus had been allowed to cool, the sodium capsule was taken out, the small glass tube removed, and the opening closed with paraffin. In this convenient form the sodium mirrors could be kept indefinitely. The method was found to work equally well with potassium, and all sodium or potassium surfaces studied were obtained in this way.

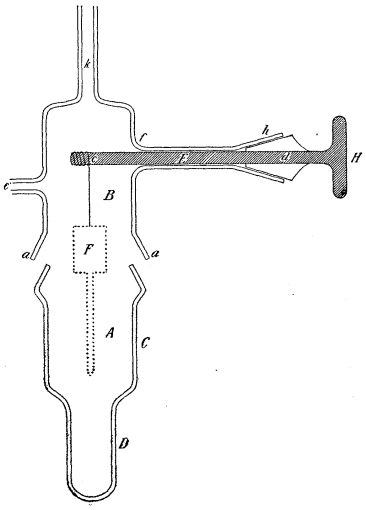

Fig. 1.

Apparatus. — The containing vessel was made of glass and consisted of two parts (*A* and *B*, Fig. 1) fitting together at *a* in a ground junction. The lower part *A* was made by sealing the tube *D*, 5 cm. long and 1.5 cm. in diameter and closed at one end, into the larger tube *C*, 7 cm. long and 4 cm. in diameter. The upper part *B*, 9 cm. long and 4 cm. in diameter, was made from a glass tube closed at one end. At *f* was sealed in a side tube, which ended in the ground cone *h*. A glass rod *E* carried a cone *d* ground to fit *h*, and by means of the T-shaped end *H*, could be rotated about the line *cd* as an axis. It thus served as a windlass to raise and lower the capsule *F* which was suspended by a cord wrapped around the rod at *c*. The wires, carrying the current used to heat the capsule, were led in through the small tube *e*, which was closed with sealing wax. A rubber tube connected the outlet *k* to a two-way stopcock, one branch of which led to the air-pump, while the other, through drying tubes, led to the outside air. The vessel *AB* could thus either be evacuated through *k*, or when evacuated, could be refilled with dry air through the same tube.

The short iron tube (*R*, Fig. 2) used in making the capsule, was 0.8 cm. in length and 1.5 cm. in diameter. A hole *a* 0.45 cm. in diameter was drilled radially through the side of the tube midway between the ends.

A fillet *s* 0.08 cm. wide and of the same depth was cut around the outside edge of each end, thus leaving the shoulder *t* on the inside edge. The end faces of these shoulders were made as plane as possible by grinding on fine emery paper backed by a surface plate. The two pieces of plane glass *gg*, after being carefully cleaned, were clamped tightly against these shoulders. The fillet along the outside edge of the metal ring, together with the adjacent glass plate, now formed a little groove which was filled with cement, while the shoulder pressing against the glass prevented the cement from creeping inside. The capsule was completed

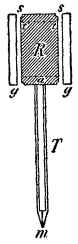

Fig. 2.

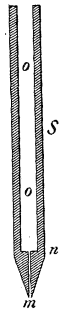

Fig. 3.

by cementing the side tube *T* into the opening *a*. It was then baked at a temperature of about 120° C. for several hours, until the cement, which was at first a light yellow, became dark brown. In some cases a tube of brass (*S*, Fig. 3) was used for the side tube *T*. It was made from a brass rod, 0.45 cm. in diameter and 5 cm. long, which was tapered at one end almost to a point. A hole *o*, 0.3 cm. in diameter, was drilled along the axis of the rod to the point *n*. Then a very small hole 0.03 cm. in diameter was drilled from *m* to *n*, to connect with the larger opening.

Precautions to Prevent Oxidation.—As the most difficult problem in the whole research was the obtaining of a surface free from oxide, the precautions taken to prevent oxidation will be described in some detail.

In preparing to make a mirror, the containing vessel *AB* was first thoroughly cleaned. It was then placed in an upright position, and the capsule (*F*, Fig. 1) suspended from the rod *E* as already described. The vessel was alternately evacuated and filled with dry air[1] a number of times, in order to remove any water vapor or other gases from the interior. Finally it was left closed, full of dry air. The vessel was further protected from moisture by a U-tube of phosphorus pentoxide, placed between it and the pump.[2]

[1] The air was dried by drawing it through U-tubes of sulphuric acid and phosphorus pentoxide.

[2] Gaede's combination of oil and mercury pumps was used.

The quantity of sodium, a part of which was to be used in making the mirror, was immersed in a light paraffin oil. By means of a cork borer of a diameter just smaller than that of the tube (*D*, Fig. 1), a cylindrical stick about 3 cm. long was cut out of the metal. Any heavy coating of oxide still adhering to the ends of the stick was removed with a knife. The cylinder of sodium, thus obtained, was quite free from oxide, since all the cutting had been done under oil. The stick was lifted out and rinsed thoroughly in benzine to remove the oil, the benzine, in turn, being removed by rinsing in toluene. Now, as quickly as possible, the glass vessel *AB* was opened, the sodium cylinder dropped into the receptacle *D*, and the vessel immediately closed and evacuated. The remaining toluene was therefore rapidly removed by evaporation at a reduced pressure. It will be noted that at no time during the whole process was the sodium exposed to the open air. In spite of all these precautions, however, a surface film of oxide would always form before the sodium was entirely melted. Therefore, in order to pierce this surface film, and to permit as little as possible of it from entering the capsule, it was necessary to make the tube (*T*, Fig. 2) pointed, with a very small opening in the end (as already described).

It was possible in this way to obtain bright surfaces, but, upon a close examination, they proved to be covered with an extremely thin filmy veil. This film, however, was not spread uniformly over the surface, but was distributed in curved and ring-like figures, leaving in a number of cases, small areas which were entirely free from it. Further experiment proved that this thin film was due to a spreading out of a small quantity of oxide which had entered the tube *T* when it broke through the surface of the molten metal.

In order to prevent this, two methods were used with about equal

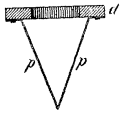

Fig. 4.

Fig. 5.

success. In the first method a wedge-shaped device was used to cut the surface film and open a way through it for the tube *T*. This device (Fig. 4) was made by fastening two very thin flat steel springs *pp*, each 1.3 cm. long and 0.5 cm. wide, to the metal disk *d* so that the outer ends of the springs were held together, thus making a sort of hollow wedge as shown in the figure. A hole, 0.6 cm. in diameter, was drilled through

the center of the disk, which was 1.2 cm. in diameter, just smaller than the inside diameter of D (Fig. 1). This was suspended from the capsule so that the tube T extended through the hole in the disk, with the pointed end inside the hollow wedge. Now as the capsule was lowered, the wedge pierced the oxide film and entered the sodium, stopping when the disk rested upon the surface of the metal. By a further lowering of the capsule, the sides of the wedge were forced apart by the pointed tube. This pushed aside the surface film so that the point of the tube could enter directly the bright surface of the metal.

In the second method a glass tube (W, Fig. 5), whose outside diameter was slightly less than the inside diameter of the receptacle D, was drawn down at one end to an opening h about 0.8 cm. in diameter. This tube was then suspended, small end downward, from the capsule (F, Fig. 1), so that the lower end of the tube W was about 1 cm. below the point m of the small tube T. When, upon lowering this contrivance, the lower end of W reached the metal some of the surface film would, of course, enter at h. As the tube W continued to descend, the liquid metal, entering through h from below, burst through and pushed aside this film (which adhered to the sides of the tube W), thus permitting the point of the tube T to enter a bright globule of melted sodium.

Both of these devices were of considerable help in obtaining bright surfaces, but neither could be said to be consistently successful. By making a number of mirrors, however, a few were obtained which were practically free from this surface film. The results given in this report were obtained from these surfaces.

Other Surface Defects.—In some cases the surface of the mirror was found to be marred by numerous fine lines along which the sodium seemed to have drawn away from the glass. These lines suggested a crystalline formation and probably had been caused by the contraction of the sodium upon solidifying. This configuration on the surface was especially noticeable when the mirror was examined with polarized light, for, since the light totally reflected from the back surface of the glass along these lines differed in phase from that reflected from the sodium surface, both could not be extinguished at the same time. Fortunately, however, only a few of the mirrors showed this defect, and they were either entirely discarded or measurements made only on that part of the surface from which these lines were entirely absent.

A number of failures proved that unless the glass plates, upon which the mirrors were to be formed, were heated to approximately the temperature of the melted sodium, the metal would solidify as soon as it touched the plates, leaving streaks or striations across the surface.

It was also found necessary to heat the tube T, through which the sodium was forced up into the capsule, for, otherwise the sodium would solidify while yet in the tube, and so never reach the glass plates. On this account a brass tube proved much more convenient than the glass one originally used, since the whole of the brass tube could be heated by merely heating the capsule.

Cement.—In making the capsule quite a little difficulty was experienced in finding a satisfactory cement, *i. e.*, one which would fasten together glass and iron in an air-tight junction and would not soften or become porous when heated in a vacuum to the required temperature (about 110° C.). A number of cements were tried, some being commercial products, while others were mixed in the laboratory according to various formulæ. The one finally selected is on the market under the trade name "Rock Cement." When first tried, this was used according to the printed directions, but was not satisfactory. Further experiment, however, showed that it could be made so if thoroughly dried by heating. It was also noticed that better results were obtained by allowing the cement to thicken somewhat by evaporation before using.

MEASUREMENTS.

Method and Apparatus.—Drude's method for obtaining the optical constants of metals was used throughout this investigation. It consists in an examination of polarized light reflected from the polished surface of the metal. If the incident light be polarized in a plane making an angle of 45° with the plane of incidence, the quantities to be measured are ϕ, the angle of incidence; Δ, the phase change introduced by reflection; and ψ, the azimuth of restored polarization. The optical constants (n, the index of refraction and κ, the index of absorption) are obtained by substitution in the following formulæ, given by Drude.[1]

$$n^2(1 - \kappa^2) = S^2 \cos 2Q + \sin^2 \phi, \tag{1}$$

$$2n^2\kappa = S^2 \sin 2Q, \tag{2}$$

where

$$\cos 2P = \sin 2\psi \cos \Delta, \tag{3}$$

$$\tan Q = \tan 2\psi \sin \Delta, \tag{4}$$

$$S = \sin \phi \tan \phi \tan P. \tag{5}$$

Writing

$$S^2 \cos 2Q + \sin \phi = A, \tag{6}$$

$$S^2 \sin 2Q = B, \tag{7}$$

then

$$2n^2 = \sqrt{A^2 + B^2} + A, \tag{8}$$

$$\kappa = \frac{\sqrt{A^2 + B^2} - A}{B}. \tag{9}$$

[1] Ann. d. Phys., Vol. 64, pp. 161–2, 1898.

The principle angle of incidence $\bar{\phi}$, the principal azimuth $\bar{\psi}$, and the reflecting power R, are given by:

$$\sin^4\bar{\phi}\tan^4\bar{\phi} = n^4(1+\kappa^2)^2 - 2n^2(1-\kappa^2)\sin^2\bar{\phi} + \sin^4\bar{\phi}, \quad (10)$$

$$\bar{\psi} = \tfrac{1}{2}\tan^{-1}\kappa, \quad (11)$$

$$R = \frac{n^2(1+\kappa^2)+1-2n}{n^2(1+\kappa^2)+1+2n}. \quad (12)$$

Since for sodium and potassium the constant A (Eq. 6) is negative, the calculations may be much simplified. Making A negative and expanding the radical, equation (8) becomes

$$2n^2 = A\left(\frac{B^2}{2A^2} - \frac{B^4}{8A^4} + \text{etc.}\right).$$

As B is small compared to A, all terms except the first may be neglected. This gives

$$n = \frac{B}{2\sqrt{A}}. \quad (13)$$

In a similar way, equation (9) may be simplified, giving

$$\kappa = \frac{2A}{B}. \quad (14)$$

In all calculations made in this report an error of less than one per cent. results from using equations (13) and (14).

As in Drude's experiments, the instrument used was a spectrometer fitted with a polarizing and an analyzing nicol and a Soleil-Babinet compensator. The desired wave-length was obtained by means of a monochromatic illuminator, the source of light being an electric arc. For each particular wave-length used, the zero position and the constant of the compensator were accurately determined.

Since the formula for n involves the tangent of the angle 2ψ, usually large, a small error in measuring this angle has a much greater effect upon the result than a corresponding variation in Δ. This is especially true of the light reflected from a sodium surface, for which 2ψ is about 89°.

A number of careful measurements, made to determine the most accurate method of setting the nicol, showed that the best results were obtained by removing the eyepiece of the telescope and looking directly at the nicol. Viewed in this way, there appeared, at the extinction point, a broad and quite black horizontal band which never entirely covered the field.[1] Upon sliding the wedge in the compensator this band would

[1] This is not the phenomenon so often noticed with crossed nicols, for the band appeared only when the compensator was in position. With the new compensator (mentioned elsewhere in this article) the field was uniform, but if the quartz plates were rotated slightly upon each other, the band appeared and became quite distinct.

move up or down in the field, while upon slightly moving the nicol in either direction from an extinction point, it would slowly fade away, usually moving across the field in the direction of its length. The cause of this unexpected appearance of the field has been traced to a fault in the construction of the compensator, the principal axes of the quartz plates not being exactly perpendicular to each other.

The extinction point for both the compensator and the nicol was taken to be that position for which the dark band was centered in the field. For the compensator, the value used for the extinction point was the mean of eight or ten settings. For the nicol, a larger number of readings was necessary, since, under the best conditions, the individual settings varied by approximately thirty minutes of arc. Therefore, in order to get readings in every possible position of both the polarizer and the analyzer the following method was adopted. The polarizer was set in four positions, each 45° from the plane of incidence. At each of these positions, seven to ten readings of the analyzer were taken for each of its two extinction points, 180° apart. Therefore the value obtained for 2ψ was the mean of 50 to 80 readings.[1]

Mounting the Mirrors.—The mirrors were mounted so as to be viewed through a prism. A drop or two of cedar oil, which had approximately the same index of refraction as the glass, was placed upon the surface of the mirror and the mirror pressed firmly against the hypotenuse side of a right-angled prism. The light entered one leg of the prism normally and, after reflection at the sodium surface, emerged normally through the other leg. By this plan all the troublesome reflections from the front surface of the glass of the mirror were avoided, and, since the light was normal to both prism faces, it suffered no change of phase or of azimuth, either at the point of incidence or emergence. In order to remove any film of grease or other foreign matter, which might cause a phase change, the mirror and all of the surfaces of the prism were carefully washed before mounting.

Tests for Possible Corrections.—Should there be a slight difference between the value of the refractive index of the cedar oil and that of the glass, a change in the azimuth of polarization would be produced at the boundary between the two media. A test for such an effect was made in two ways, as follows:

First, a piece of plate glass was fastened with the cedar oil to the hypotenuse side of the prism. Polarized light was sent through the prism in the same way as before, but was now totally reflected from the

[1] A new compensator combined with a half shadow analyzer (Zehnder, Ann. d. Phys., Vol. 26, p. 985, 1908) has since been received from Germany, and the few measurements taken with it agree closely with those reported in this paper.

back surface of the glass plate. A careful examination of this light which, it will be noticed, had passed twice through the oil film, each time at an angle of 45°, showed no change in the azimuth of polarization. The phase change was also measured and found to agree closely with that to be expected from total reflection.

Secondly, five square pieces of glass, cut from the plate used in making the sodium mirrors, were placed between 60° prisms as shown in Fig. 6. A drop of cedar oil was placed between each plate, and between the first and last plates and the prism faces, and the whole pressed firmly together. Polarized light was sent through the combination in such a way as to pass normally through the outer prism faces (as indicated in the figure). The light therefore traversed twelve surfaces of contact between glass and oil, the angle at each being 60°. Here again a careful set of measurements failed to show any change in the azimuth of polarization. Hence, any effect, if present, must be negligible.

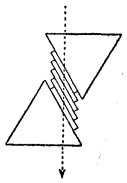

Fig. 6.

Another possible source of error was the presence of the oxide film, of which, as already mentioned, almost every sodium mirror showed at least a trace. In order to determine the optical effect of this film, the phase change and restored azimuth were measured on six different sodium mirrors. A week later a second set of measurements were made on the same surfaces. In the results, which are given below (Table I.), the phase change is expressed in head divisions of the micrometer screw and may be reduced to degrees by multiplying by 0.3937. The numbers given in the first column are used merely to distinguish the individual surfaces.

TABLE I.

Mirror No.	Phase Change.			Azimuth.		
	1st.	2d.	Av.	1st.	2d.	Av.
1	329	327	328	89° 21′	89° 23′	89° 22′
2	322	334	328	89° 20′	89° 24′	89° 22′
3	310	306	308	89° 6′	89° 13′	89° 10′
4	320	305	312	89° 3′	88° 54′	88° 58′
5	330	329	329	88° 54′	89° 3′	88° 58′
6	316	317	317	88° 50′	89° 0′	88° 55′

The results have been arranged in the above table in descending order of the average azimuth, and an examination of the individual surfaces showed that in general the film became more pronounced in the same order. No such variation of phase change could be observed. A com-

parative study of the first and second columns in both the phase change and azimuth above indicates no consistent change in the surfaces during the week which elapsed between the two sets of readings.[1]

As Nos. 1 and 2 were practically free from film, they were chosen for the determination of the optical constants of the metal as given below. It is believed that the results obtained from these mirrors are very near to those that would be obtained from a perfect surface, since the rather heavy film on Nos. 5 and 6 reduced the azimuth by less than thirty minutes.

Nos. 1, 3 and 4 were made from (Merck) sodium, guaranteed to be free from other metals, while Nos. 2, 5 and 6 were made from ordinary commercial sodium. The results did not show any consistent difference between the two specimens of the metal.

It is interesting to note that Nos. 5 and 6 were mirrors on the opposite sides of the same capsule. No. 5 was made directly on the hypotenuse face of a prism (by substituting a prism for one of the glass plates of the capsule), and so could be examined without the use of the oil film, while No. 6 was formed on the glass plate and examined through the oil. The results indicate that the oil film had no appreciable effect.

Method Applied to Mercury.—Exactly the same method was used throughout to determine the optical constants of mercury. As the constants for this metal are well known the results (Table II.) serve as a check upon the method. It will be noticed that the values for n are slightly higher than those obtained by Drude[2] or by Meier.[3] This may be due to the particular specimen of mercury used.

TABLE II.

Mercury. $\phi = 45°$.

λ	Δ	2ψ	n	κ
6,650	162° 11′	82° 57′	2.34	2.47
5,893	160° 4′	83° 1′	1.92	2.78
4,720	156° 14′	83° 18′	1.35	3.42

Former values obtained are:

Drude, $\lambda = 5{,}893$, $n = 1.73$, $\kappa = 2.87$.
Meier, $\lambda = 5{,}893$, $n = 1.62$, $\kappa = 2.71$.

Specimen Set of Readings in Detail.—In order to give an idea of the accuracy of setting and the method of procedure, a complete series of readings, taken to determine a single value of n and κ, is given in Table III. Every result was determined from a similar series of readings.

[1] Measurements taken on some of these surfaces three months later showed no change in the character of the surface.

[2] Ann. d. Phys., Vol. 39, p. 530, 1890.

[3] Ann. d. Phys., Vol. 31, p. 1031, 1910.

TABLE III.

A. Determination of Zero Point and Constant of Compensator.

Sodium mirror No. 1. $\phi = 44° 59'$,

	For Phase Difference of		
	-2π	Zero.	$+2\pi$
	(0) 80.0	(12) 37.0	(23) 91.0
	81.0	36.0	95.0
	79.2	36.0	98.0
	81.0	38.5	99.0
	78.3	38.0	(24) 1.0
	81.0	38.0	(23) 95.0
	78.2	36.5	96.2
Averages.....	(0) 79.8	(12) 37.0	(23) 96.3

Numbers in ( ) indicate whole number of turns of the micrometer screw. The readings are in head divisions.

2,316.5 divisions = 720° (4π). Therefore 1 div. = 720/2,316.5 deg.

B. Determination of Phase Change upon Reflection.

Readings for Extinction	
At Beginning.	At End of Series.
(16) 90.0	(16) 81.5
89.0	83.0
88.0	84.2
86.0	84.0
86.5	82.5
87.2	85.0
88.6	86.0
Av. (16) 87.9	(16) 83.7

1,685.8 − 1,237 = 448.8 divisions.

Therefore $\Delta = 139° 29'$.

General average, 1,685.8.

C. Determination of Restored Azimuth.

Polarizer.	49° 39'		229° 39'	
Analyzer.....	360° 9'	179° 29'	179° 48'	359° 42'
	359° 22'	179° 17'	180° 7'	359° 40'
	359° 30'	180° 2'	180° 31'	359° 42'
	360° 20'	179° 4'	180° 32'	359° 4'
	360° 8'	179° 33'	179° 46'	359° 40'
	359° 59'	179° 23'	179° 44'	359° 32'
	360° 11'	179° 52'	179° 40'	359° 46'

General average (reduced to one position), 359° 46.2'.

Polarizer.	139° 39'		319° 39'	
Analyzer.....	270° 40'	90° 53'	90° 27'	270° 1'
	270° 24'	90° 9'	90° 22'	270° 14'
	270° 22'	90° 18'	90° 28'	270° 53'
	270° 1'	90° 32'	89° 48'	270° 11'
	270° 24'	90° 28'	90° 28'	270° 31'
	270° 11'	90° 9'	89° 53'	270° 10'
	270° 42'	90° 19'	90° 2'	270° 54'

General average, 270° 20.9′. Therefore $2\psi = 89° 25.3'$.
By substitution $A = -3.1553$, $B = 0.1135$. Giving $n = 0.032$, $\kappa = 55.6$.
Index of refraction for glass plate = 1.5 (approximately).[1]
Therefore the index of refraction from air to sodium is:

$$n = 1.5 \times 0.032 = 0.048.$$

RESULTS.

TABLE IV.

Sodium.

Sodium mirror No. 1. $\phi = 44° 59'$.

λ	Δ	2ψ	n	κ
6,650	139° 29′	89° 25.3′	0.048	55.6
5,893	134° 46′	89° 22.9′	0.042	54.3
5,460	130° 34′	89° 14.1′	0.045	44.7
4,720	124° 34′	89° 0′	0.051	34.2
4,350	117° 58′	88° 46.7′	0.053	26.4

Sodium mirror No. 2. $\phi = 44° 59'$.

λ	Δ	2ψ	n	κ
6,650	142° 1′	89° 25.9′	0.053	54.5
5,893	137° 10′	89° 24.7′	0.045	55.8
5,460	136° 6′	89° 9.8′	0.060	40.6
4,720	130° 20′	88° 57.5′	0.062	32.4
4,350	127° 7′	88° 32.0′	0.063	37.0

The averages from the above are given in the second and third columns below. The values of $\bar{\phi}$, $\bar{\psi}$, and R, given in the last three columns, are obtained by using these averages in the formulæ (10), (11), and (12).

λ	n	κ	$\bar{\phi}$	$\bar{\psi}$	R
6,650	0.051	55.0	72° 11′	44° 29′	97.7
5,893	0.044	55.0	68° 51′	44° 29′	97.1
5,460	0.052	42.6	68° 48′	44° 20′	96.5
4,720	0.057	33.3	66° 29′	44° 9′	95.2
4,350	0.058	31.7	66° 0′	44° 6′	94.8

TABLE V.

Potassium.

Potassium mirror No. 1. $\phi = 44° 59'$.

λ	Δ	2ψ	n	κ
6,650	123° 23′	88° 49.7′	0.057	28.2
5,893	116° 26′	88° 36.7′	0.059	22.7
4,720	106° 18′	88° 27.6′	0.060	15.5

[1] Any error in this approximation is within the limits of experimental error.

Potassium mirror No. 2. $\phi = 44° 59'$.

λ	Δ	2ψ	n	κ
6,650	128° 29′	88° 39.0′	0.075	25.4
5,893	123° 19′	88° 25.5′	0.077	21.6
4,720	114° 19′	88° 5.2′	0.079	13.1

Averages, etc.

λ	n	κ	$\bar{\phi}$	$\bar{\psi}$	R
6,650	0.066	26.8	65° 27′	43° 56′	93.8
5,893	0.068	22.1	62° 58′	43° 42′	92.0
4,720	0.070	14.3	57° 9′	43° 0′	86.9

Although the two potassium mirrors studied seemed to be entirely free from the oxide film, the results are not considered conclusive until more surfaces have been examined. No explanation is offered, at present, for the difference in the results obtained from the two specimens.

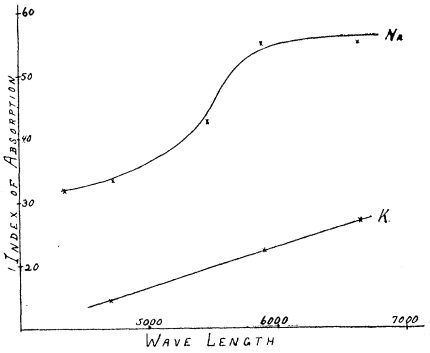

Fig. 7.

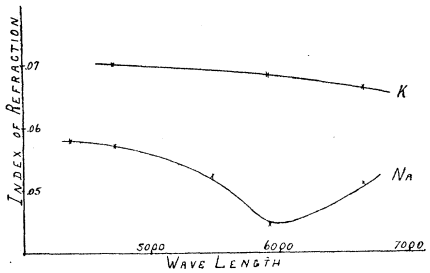

Fig. 8.

The variations of the optical constants with wave-length are shown in Figs. 7 and 8. The curve for the index of refraction of sodium has a distinct minimum near the D-line.

Conclusions.

1. It is possible to obtain and preserve indefinitely bright surfaces of both sodium and potassium.

2. Metallic sodium has the lowest index of refraction and the highest reflecting power of any metal known. This is in agreement with Drude's observations. It is interesting to note that the value for the refractive index for sodium light is very near (slightly less than) the upper limit set by Drude.

3. While the refractive index for sodium is very low for all wavelengths, it apparently has a minimum close to the sodium line.

4. Next to sodium, potassium has the lowest index of any metal. Its reflecting power, however, is slightly less than that of either silver or sodium.

5. The method seems applicable to the sodium-potassium alloy, and possibly may be adapted to other highly oxidizable substances. By using quartz, or uviol glass, plates and prisms the investigation may be carried into the ultra-violet by means of Minor's method.[1]

While the results reported above seem to be fairly consistent among themselves, the authors intend to verify them by further investigation. They hope, also, to be able to determine the optical properties of the sodium-potassium alloys, and probably of some other substances, to which the same method is applicable.

In conclusion we wish to acknowledge our indebtedness to Professor Arthur W. Goodspeed, who placed at our disposal all the facilities of the laboratory and kindly procured for us additional apparatus. We wish also to thank Professor Horace C. Richards for suggesting the subject of this research and for his continued interest and coöperation.

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[1] Ann. d. Phys., Vol. 10, p. 581, 1903.